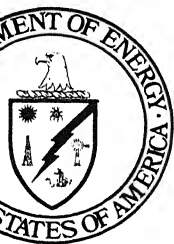


Report on the Concept Review Committee Recommendations for Proof-of-Principle Alternate Conce Programs

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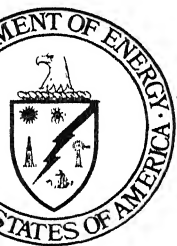


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Advanced Fusion Concepts Branch

Report on the Concept Review Committee Recommendations for Proof-of-Principle Alternate Concepts Programs

March 1979



Prepared by

U.S. Department of Energy

Assistant Secretary for Energy

Advanced Fusion Concepts Branch

Office of Fusion Energy

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FOR PROOF-OF-PRINCIPLE ALTERNATE CONCEPT PROGRAMS

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Introduction

The recently announced DOE policy statement on the development of fusion energy places increased emphasis on the testing of promising alternate concepts. More specifically, this policy suggests comparisons of promising alternatives with tokamaks and mirrors in the mid 1980's. In order to make these concept comparisons, it is necessary to extend greatly the scientific data base for the alternate concepts toward the reactor regime to provide significant experimental tests. These significant tests have been designated as proof-of-principle (POP) experiments and have most of the important dimensionless parameters in or near the reactor regime. A POP experiment for an alternate concept can be considered the scientific equivalent of PLT in the tokamak program.

The initiation of POP programs has been divided into a two-step process. The first step is a policy making step: concept selection as addressed by the review described in this report. The second step, selection of contractors to fabricate and operate POP experimental devices, is a procurement action, and is presently underway.

A DOE Concept Review Committee (CRC) was established to examine candidate concepts for POP experiments and to make recommendations to the Director of the Office of Fusion Energy on concept selections for initiation of POP experiments to begin operation before the mid 1980's. Membership on the CRC consisted of:

J. F. Decker (Chairman)
W. F. Dove
W. R. Ellis
R. Kostoff
J. Mayo
E. Oktay

At the outset, a wide spectrum of recommendations seemed possible -- one extreme being that several concepts are very promising and are ready to make the move immediately to a POP experiment; another extreme being that no concept is sufficiently advanced or promising to be recommended for a POP program at this time. The whole spectrum of possible recommendations between those two extremes was considered.

The CRC solicited nomination of concepts for POP consideration from contractors, noncontractor institutions known to be interested in magnetic fusion and the general public via mailings and with an announcement in the Federal Register in August, 1978. This solicitation invited maximum public input for the concept selection process. Written material on candidate concepts was submitted to the CRC and its advisors and technical consultants by proponents and other interested parties during September and October 1978. Oral presentations were heard from concept proponents in a public

Following the public meeting, the technical consultants and advisors provided technical advice and input to the CRC by (1) evaluating each concept for eligibility for a Proof-of-Principle experiment at this time, and (2) by answering specific questions on:

- the reactor desirability of the concept
- the physics and technology confidence in both the reactor and the POP experiment
- cost and schedule data for the POP experiments

Based on consideration of the above information and some programmatic issues, the CRC developed its own findings and recommendations. These recommendations were forwarded to the Director of the Office of Fusion Energy, DOE, on October 27, 1978. The CRC recommendations were approved by the Director, in November, 1978, and concurred in by the senior management of DOE in December 1978. These recommendations thus constitute the policy of DOE and ETM with regard to "level 1" alternate fusion concepts.

The purpose of this report is to publicize the CRC recommendations, and to provide background information on the concept review process and the role of level-1 (proof of principle) experimental activities within ETM's alternate concepts program.

The report is organized as follows:

Section II contains a discussion of the meeting procedures used on October 16-18, 1978, and the rules employed for technical consultants and advisors to the CRC.

Section III contains a discussion of the CRC recommendations and some of the factors taken into consideration by the Committee.

Section IV briefly discusses "where do we go from here?" in DOE's alternate concepts program.

The Federal Register announcement of the October 16-18, 1978 meeting is given in Appendix A. The text of the opening remarks by the CRC Chairman is given in Appendix B. A full reproduction of the CRC recommendations is given in Appendix C.

II. Procedures followed at the October 16-18, 1978 Review Meeting

A. Federal Register Announcement - see Appendix A.

A few points should be made to emphasize the procedures announced in the Federal Register for the Alternate Concepts Review Meeting.

1. The meeting was set up to deal with concept evaluation and review, and specifically excluded contractor or site evaluation and review. The purpose of the meeting was to determine policy matters and not to deal with procurement.

2. Proposals were not solicited, or accepted, as a part of this review process. All material submitted was for the use of the CRC in reaching its determinations. Further, it was announced at the start of the meeting (see Appendix B) that proposals dealing with any of the concepts under review would not be reviewed, or even read, by members of the CRC until the completion of the committee's work.

3. The Concept Review Committee and DOE did no pre-screening of concepts for consideration at this review. All presenters who asked for consideration were given a place on the agenda. It was clear following the presentations that some of the concepts presented were not in a defensible position for a major proof-of-principle experiment being insufficiently developed or otherwise ineligible for participation according to the guidelines published in the Federal Register Announcement. Accordingly, an eligibility test was applied to each concept (described in more detail below).

B. Advisors

The CRC utilized an in-house group of advisors from within the Office of Fusion Energy to aid them in (1) formulating the concept review process, (2) selecting technical consultants, (3) developing concept selection criteria, and (4) aiding the CRC in its analysis. The technical advisors are listed below:

R. Blanken - Division of Magnetic Confinement Systems

C. Head - Division of Development and Technology

A. Kadish - Division of Applied Plasma Physics

M. Murphy - Division of Development and Technology

C. Technical Consultants

In addition to the DOE advisors, the CRC utilized a group of technical consultants from universities, industry, utilities DOE laboratories, and foreign research centers. The consultants were chosen for their expertise in plasma physics, fusion reactor designs, and fusion related technologies. Their detailed evaluations of the concepts were a major source of input to the CRC in reaching its conclusions. The technical consultants are listed below:

- N. Amherd - Electric Power Research Institute
- C. Baker - Argonne National Laboratory
- I. Bernstein - Yale University
- A. DeSilva - University of Maryland
- J. Gilleland - General Atomic Company
- H. Grad - New York University
- V. Granatstein - Naval Research Laboratory
- W. Grossmann - New York University
- R. Hancox - Culham Laboratory
- C. Hartman - Lawrence Livermore Laboratory
- D. Kearny - General Atomic Company
- R. Kribel - Auburn University
- J. Leiss - National Bureau of Standards
- R. Lovberg - University of California, San Diego
- E. Puhn - General Atomic Company
- M. Rosenbluth - Institute of Advanced Study
- A. Smith - Pacific Gas and Electric Company
- A. Ware - University of Texas

Procedural matters were also discussed in the introductory remarks by the CRC chairman, Dr. J. F. Decker, on October 16, 1971. The meeting was then turned over to Dr. P. Stone, who presided over the remainder of the meeting. Dr. Decker's remarks are reproduced in Appendix B.

D. Concept Selection

A total of nine concepts were presented to the CRC at the meeting for consideration. These nine were the:

LIST OF PRESENTERS AND CONCEPTS

<u>CONCEPT</u>	<u>ORGANIZATION</u>
DIWELLOR	FUSION ENERGY CORPORATION
EBT	ORNL/TRW INC/MCDONNELL DOUGLAS
PLASMA-MANTLE-KERNEL	PROMETHEUS INC.
ION LAYER	INDIVIDUAL
LINEAR MAGNETIC FUSION	MSNW INC.
MULTIPOLE/SURMAC	UCLA/TRW INC/WISCONSIN
PYROSPHERE	PYROSPHERE INC.
REVERSED FIELD PINCH	LASL
STELLARATOR/TORSATRON	MIT/WISCONSIN/PPPL

The EBT, Stellarator/Torsatron, RFP, and Multipole/Surmac had more than one institutional proponent and in these cases different approaches to the POP experiments were discussed. The CRC believes that all alternate concepts which are serious contenders for a POP-level test at this time (and some which were not) were considered in this review.

The technical consultants were requested to evaluate each candidate concept on the basis of (1) basic eligibility for a proof-of-principle test, (2) reactor attractiveness, (3) physics confidence, (4) technology confidence, and (5) cost and schedule. The consultants were divided into three groups according to their expertise and background to address areas (2)-(5). The CRC and its advisors met with the technical consultants on October 16 prior to the public meeting. At this meeting each consultant was provided with written instructions for evaluating each of the five areas. In addition, some verbal instructions were given, as follows:

- Each consultant was requested to provide individual comments rather than group evaluation.
- Each consultant was requested to evaluate the basic eligibility of the concept.
- Each consultant was requested to concentrate on the specific area of evaluation to which he was assigned although his comments on other areas would be welcome.
- It was recommended that the consultants in evaluating their assigned area should concentrate on those concepts which they believed would pass the basic eligibility test.

The primary reason for these instructions was to reduce the total number of issues to be addressed by each individual consultant and thereby improve the quality of the contributions.

Following the public meeting on October 18, the consultants divided into three groups (dealing with physics issues, reactor issues, and technology issues) to discuss issues related to their particular area of concern. These groups also met for a brief time on October 19. Some of the consultants remained through October 20. A CRC member attended every meeting of the consultants. Following the division of the consultants into three separate working groups, one member of the CRC attended each group in the capacity of chairman. Following the group meetings, the consultants completed their individual assessment of each concept and submitted them to the CRC.

Following the meetings with the consultants and advisors, the CRC met in executive session for seven days, beginning on October 19. During this time, the CRC studied the available documentation, consultants questionnaires, advisors' reports, and comments from the public (received before and after the public meeting), and prepared its report.

The CRC submitted unanimous recommendations to the Director of the Office of Fusion Energy on October 27, 1978 (see Appendix C).

II. Discussion of CRC Recommendations

The evaluation of candidate concepts was handled in a two-step process. In the first step, candidate concepts were judged on the basis of their eligibility according to the ground rules covered in the August 1978 Federal Register Announcement. The second step, inherently more complex, involved a judgement as to whether the concepts which were eligible were in fact attractive enough and well developed enough to justify initiating a proof-of-principle program at this time. These evaluations are discussed in more detail below.

A. Eligibility Evaluation

The essence of the eligibility requirement was that a concept be sufficiently mature, from a technical standpoint, that a proof-of-principle experiment at this time could be regarded as a logical next step in the concept's development. Concepts requiring an intermediate experiment or other research to define the critical issues before a proof-of-principle experiment could be designed with reasonable confidence were explicitly excluded from this review by the Federal Register Announcement. Most proponents of alternate concepts abided by this rule. At the public meeting, however, it was evident that some presentations included ideas which had received as yet little or no experimental verification. The first test given to all candidate concepts was, therefore, a basic eligibility test, worded as follows:

"Determine if the concept as presented:

1. Appears to show promise for a fusion reactor and does not (clearly) fall within the tokamak or mirror fusion programs.
2. Does not require an intermediate step to define critical issues.
3. Possesses sufficient definition of critical issues to allow specification of definitive tests; has a physics data base which is deemed sufficient to allow design of a POP experiment which has a reasonable probability of providing a definitive test of the concept.
4. Can be operated in the 1982-83 time frame."

All nineteen consultants were asked to apply the eligibility test to each of the nine concepts reviewed. The results are given in the following table:

Eligibility Test
 (Is the Concept Eligible?)
 (Tabulation of Consultants' Votes)*

<u>Concept</u>	<u>Yes</u>	<u>Uncertain</u>	<u>No</u>
EBT	17	1	0
RFP	13	1	3
Stellarator/ Torsatron	8	0	10
LMF	6	0	10
Multipole/Surmac	2	0	15
Ion Ring	0	0	13
PMK	0	0	17
Diwellor	0	0	17
Pyrosphere	0	0	17

(*The varying numbers reflect the actual number of questionnaires turned in.)

The evaluations of the CRC members and the DOE advisors were in good agreement with those of the consultants on the question of eligibility. As a result of these eligibility evaluations, the CRC classified the nine candidate concepts into three categories as follows:

- First Category - those concepts judged to be potentially eligible for a proof-of-principle experiment by an overwhelming majority of the CRC members and its consultants and advisors. Two concepts - EBT and RFP - fall into the First Category.
- Second Category - those concepts whose readiness for a proof-of-principle experiment at this time is more questionable on technical grounds. Two concepts - Stellarator/Torsatron and LMF - fall into the Second Category.
- Third Category - those concepts judged definitely not ready for a proof-of-principle experiment at this time. Five concepts -- Multipole/Surmac, Ion Ring, PMK, Diwellor, and Pyrosphere -- fall into the Third Category.

The remainder of the remarks in the CRC recommendations, and in the present discussion of these recommendations, is limited to the concepts which fall into the First and Second Categories: EBT, RFP, Stellarator/Torsatron, and LMF.

B. Desirability Evaluation

The relative merits of the EBT, RFP, Stellarator/Torsatron, and LMF concepts as fusion reactors were considered by the CRC and its advisors and consultants.

After a consideration of all factors, the CRC reached the following conclusions:

1. EBT

An aggressive but systematic course of action leading to an EBT POP experiment should be initiated. The CRC recommended (a) expansion of the existing theoretical, experimental and reactor study programs, (b) initiation of design activities for an EBT POP experiment, and (c) support for the necessary gyrotron microwave tube development.

The CRC recommended that EBT design studies proceed on the assumption that the scheduled near-term EBT-S scaling studies will be successful. The design studies should allow for both ECRH and direct ion heating, including rf and neutral beams. An early test of rf ion heating on EBT-S should be examined. No funds should be committed to POP device fabrication until all device options have been thoroughly examined and agreement is reached with DOE on basic design features. A thorough peer review of the proposed EBT POP facility should be conducted. All available cost-saving methods should be considered to reduce required DOE funding commitments.

2. RFP

Research on the RFP should be continued at LASL with the completion and operation of ZT-40, because of its potential contribution to the fusion program. However, it is the CRC's recommendation not to initiate a large RFP POP program in the U.S. at this time because the CRC finds the RFP to be less attractive overall than the EBT as a reactor concept.

The Advanced Fusion Concepts Branch should work with LASL to examine the goals of ZT-40 to assure maximum relevance to the RFP program. The RFP configuration is near a minimum energy state for the combined plasma/magnetic field system and should provide important fundamental information on axisymmetric toroidal confinement and configurations (such as for Tokamak) which could improve our designs for reactor configurations. Also, the RFP offers an important potential advantage of ohmic heating to ignition, which should be exploited.

In the U.K., the RFX device at Culham (est. approximately \$20M) is awaiting final approval. The next step in the RFP program beyond ZT-40 and HBTX-1A might be filled by RFX. The CRC recommended that cooperation between the U.S. and the U.K. (or Euratom as appropriate) be explored for RFP research. A maximum cooperation might include direct U.S. support for RFX in the form of diagnostics, hardware, and/or personnel.

If the U.S. contribution to RFX is to be large, then RFX should be redesigned to carry up to 3-4 MA as a step to ensure a true POP-level test of the concept. This DOE collaboration with the RFX program could lead to maximum results with minimal investment of U.S. DOE funding.

3. S/T and LMF

Further research is needed to resolve some key issues on both LMF systems and Stellarator/Torsatron before proceeding further with these concepts. Both concepts are possibly qualified for POP experiments in some respects, and therefore, during the coming months the Advanced Fusion Concepts Branch should further evaluate available options and determine an appropriate course of action for these concepts as part of the management of the alternate concepts program.

4. Other

The other five concepts, i.e., Ion Rings, Pyrosphere, Diweller, Plasma-Mantle-Kernel (PMK), and Multipole/Surmac (M/S), having been judged not ready for POP experiments at this time, should be handled as part of the routine alternate concepts program management (see Section IV).

With respect to First and Second Category concepts, the CRC further noted the following points:

EBT

EBT offers a number of features that potentially may lead to an attractive fusion reactor. Among these are: steady state operation, modularity, easy access for maintenance, simple magnetics, absence of axial current (i.e., removal of one source of free energy), absence of disruptions, and potential availability of several heat options. Some disadvantages of an EBT reactor are scaling laws which may preclude small unit sizes (i.e., less than 750 MWe), possible difficulties with ash and impurity control which could preclude steady state operation, and the necessity of driving the rings continuously. The EBT reactor was judged to be attractive in DOE's 1977 evaluation of alternate concepts and was again judged to be so by the CRC's consultants. The EBT reactor shows promise for overcoming some of the alleged disadvantages of tokamak reactors, namely pulsed operation, poor access, and difficult maintenance.

Examination of the proposed POP experiments indicates that the critical physics issues of the EBT concept are well defined and that the POP experiment can be designed to test all or nearly all of the critical issues. Further important experimental results from EBT-S are expected in the near future. The main technology concern of the POP experiment which could adversely affect the schedule is the development of high power, high frequency (~ 100 GHz) CW gyrotrons for electron cyclotron plasma heating (ECRH).

There are several important programmatic considerations associated with initiation of an EBT POP experiment. At the present time, only two bumpy torus devices employing EBT features exist, EBT-S at ORNL and a bumpy racetrack device at

Nagoya, Japan. The U.S. program has pioneered this concept and there are no known plans to initiate large POP-type EBT experiments in other countries to make major contributions to the development of this concept. There are several spinoffs from an EBT POP experiment that would benefit the rest of the U.S. magnetic fusion program: (1) the high frequency gyrotrons would be useful for tokamaks and other concepts; (2) operation of a significant sized toroidal system with superconducting toroidal field magnets would benefit other toroidal concepts; and (3) steady-state operation of a confinement device with hot fusion-grade plasmas would address physics and technology issues associated with long-pulse device operation.

In the alternate concepts program, the CRC found the EBT to be the most ready for a POP test at this time. The CRC found the EBT to be a truly alternate toroidal concept, and to have desirable reactor features that potentially make it more attractive than a tokamak. The CRC noted that an EBT POP experiment will provide several important programmatic benefits to the rest of the fusion program, through operation of a steady-state, hot plasma confinement device, operation of superconducting toroidal field magnets, and the development of high frequency and radio frequency heating technologies.

RFP

An RFP reactor was found to have certain attractive features such as the possibility of ohmic heating to ignition, batch burn capability (which eases refueling and ash removal), low stresses on the superconducting coils, better accessibility than tokamaks, and low probability of disruptions. However, there are some offsetting disadvantages: a single heating method (ohmic) with no viable backups at this time, the requirement of an efficient energy transfer system, the need for feedback control during startup, the close proximity of the Cu shell to the plasma, anticipated difficulties with cyclic fatigue, and uncertainties in how to control wall impurities. The net result is that, while the RFP reactor may offer some significant alternatives, it does not appear to offer clearly substantial engineering advantages over tokamaks. This assessment could change if RFP physics experiments prove very successful and/or innovative engineering designs improve the reactor configuration.

The RFP, however, is of considerable interest from a physics viewpoint. Specifically, the RFP configuration is near a minimum energy state for the combined plasma/magnetic field system and may well provide important, fundamental information on axisymmetric toroidal confinement configurations (of which the tokamak is one) which could change our approach to reactor designs for such systems. The RFP POP experiment as discussed by LASL personnel, would test, among other issues, the physics of establishing and maintaining a reversed field configuration by self-reversal. The consensus of the CRC, and its consultants and advisors, is that a large experiment will be required to test these ideas and that a device capable of axial currents in the several megampere range is necessary.

However, taking all factors into consideration, a case has not been made to initiate a large RFP program in the U.S. at this time.

There are existing RFP research programs in Japan, the U.K., Italy, and the U.S. Small devices have been or are operating in each country. The U.K. and the U.S. are each fabricating moderate sized devices; the U.K., HBTX-1A (0.4 MA) at Culham, and the U.S., ZT-40 (0.6 MA) at LASL. In addition, Culham is now awaiting final U.K. government approval of funds to initiate fabrication of a new, larger experiment (RFX) with an initial current capability of 0.5-1 MA. The Physics of the RFP configuration is related to that of other axisymmetric toroidal concepts such as the tokamak and spheromak. Some of the physics learned from an RFP POP experiment would undoubtedly aid the development of such related concepts.

Stellarator/Torsatron

The torsatron reactor is a limited alternative to tokamak reactors. It has some advantages over tokamaks such as steady state operation (reduced energy storage and transfer problems and thermal stress fatigue problems), absence of large ohmic currents (eliminates current drive instabilities), large aspect ratio (allows modularity and ease of maintenance), and a natural "built-in" divertor action. Some of these reactor advantages are offset, however, by technological problems associated by this concept. For example, modularity dictates

either a large number of joints in the assembly of the helical superconducting coils or removability of the wedge-shaped vessel/shield/blanket segments through these coils. There might be serious problems with access for neutral beams and divertors. While the torsatron coils are characterized as being in a force-free configuration, the forces on these conductors might be excessive under fault conditions. At the moment, the plasma beta limitations are not known. Torsatrons might have β 's as low as in conventional tokamaks ($\sim$ a few percent).

A primary concern of the CRC with the Stellarator/Torsatron concept for a POP experiment was that adequate studies have not been carried out to define more carefully the critical issues and to improve the understanding of equilibrium, stability and transport properties. The general consensus of the reviewers was that adequate theoretical and computational methods are available which can be applied to study these issues in more detail before we embark on a POP program. When possible, the results of these studies should be verified first on smaller devices in some of the existing facilities throughout the world.

The following possibilities for action, at least, exist for the Stellarator/Torsatron concept:

- (a) Assess and review the feasibility of converting PLT into a Stellarator/Torsatron configuration. Such a conversion might be a cost-effective way to obtain experimental information on some of the physics issues such as confinement of energetic particles, bootstrap currents, scaling laws, and MHD behavior at an early time. There exists extensive operational experience with the PLT system and its neutral beams, and with a wide range of diagnostics on this device. Such a program, together with theoretical and computational efforts, could provide significant information on the Stellarator/Torsatron approach.
- (b) Carry out theoretical and computational studies in specific areas required for clarification of this concept's viability for a fusion reactor. The two large-device design studies, for TOREX and WISTOR, are near completion. These studies include detailed computations for the design of the facilities. A comprehensive review of these designs should reveal what aspects of the design are lacking in relevant information and provide guidance to the next level of studies. If these additional studies are encouraging, then a POP experiment should be reconsidered.

(c) A joint program with the Japanese and possibly with other countries can be considered for a large superconducting Stellarator/Torsatron experiment. A next step in torsatron research beyond the currently operating or planned Stellarator/Torsatron experiments (CLEO in the U.K., Wendelstein VII at Garching, L-2 at the Lebedev, and Heliotron-E in Japan) would presumably be a large, steady-state device. The experimental devices listed above should be adequate to investigate the near term physics issues and provide guidance for such a next-step facility. The Japanese government has shown interest in joint planning (with the U.S. and others) of alternate fusion research devices, and an advanced Stellarator/Torsatron would be a logical concept to consider for this purpose. Possibilities should be explored for inclusion of Euratom and Soviet Laboratories in such a program because of these laboratories' interest and present involvement in Stellarator/Torsatron research. Programmatic considerations in EURATOM will supposedly result in shutting down CLEO in the U.K. and the concentration of European stellarator research at Garching. Garching is presently involved in studies on the characteristics of the next-step device in stellarator research. If all such activities were to be coordinated, it should be possible to develop a coherent stellarator/torsatron research effort in the world fusion community. The exchange program envisioned by the U.S. Stellarator Advisory Committee, if implemented, could serve as a building block for the international stellarator program.

All of the above possibilities should be considered by the Advanced Fusion Concepts Branch as part of its management of the Stellarator/Torsatron program.

Linear Magnetic Fusion

Fusion reactors based on the linear magnetic fusion concept are potentially attractive because of their modularity and general simplicity.

However, such systems suffer from end-loss effects (both particle and energy) which are potentially "fatal flaws" for the concept, and which can easily result in very long reactors (in excess of km).

Also, the currently proven method of implosion heating of linear systems requires pulsed power systems which potentially involve technological problems. The feasibility of CO₂ laser heating has been demonstrated but not at plasma parameters adequate to show its applicability to reactors. There are other heating techniques such as rf or e-beam heating that could be applicable for LMF reactors but there is little experimental information to assess their ultimate potential.

It is the opinion of the CRC that, while the primary physics problem is identified (end-loss), the confinement scheme to address it is not well enough posed to permit design of a POP experiment. There are ongoing experimental programs on end-stoppering (material plugs on S-IV-P at LASL, multiple mirrors on a 10-m device at UCB, and cusp-end-stoppering at the University of Washington); and on CO₂ laser heating (MSNW) and rf heating (University of Washington). The results from these experiments should be available within the next two years, which will help determine whether there is a plausible axial confinement technique to be investigated at the POP level. Meanwhile, the linear systems represent a proven confinement geometry in search of some specific inventions to allow extrapolation to the next step.

IV. Alternate Concepts Program Management

The management and funding of the alternate concepts program within DOE falls within the purview of the Advanced Fusion Concepts (AFC) Branch, Division of Applied Plasma Physics, Office of Fusion Energy. The staff of the AFC Branch is listed below:

William R. Ellis, Chief
William F. Dove
James M. Turner
Eileen Ruby, secretary

During the first quarter of FY 1979, the Advanced Fusion Concepts program was reviewed and revised in line with the recently issued DOE policy statement on the development of fusion energy, taking into consideration new developments in fusion. The management approach followed by the AFC Branch is described briefly below.

A. Program Logic

The program rationale and management strategy for the Advanced Fusion Concepts program have been reviewed and changed to reflect recent technical advances in the magnetic fusion program. The program rationale is based upon a high degree of confidence that the scientific feasibility of fusion will be demonstrated by tokamaks. ETM's confidence in tokamaks is based on a number of promising experimental and theoretical results such as the recent high temperature experiments in PLT. Consequently, the main motivation for research in the alternate concepts area is to develop attractive reactor candidates that have potentially high commercial payoff and which represent true technical alternatives to tokamaks and mirrors. The alternate concepts, generally speaking, are at a relatively early stage of development, are more speculative than the main lines, and have a higher risk of failure. The testing of the most promising alternate concepts will help ensure that the best possible reactor approaches are available for development into commercial reactors. This approach contrasts with previous thinking where alternate concepts were largely developed as scientific backups in case tokamaks failed for physics reasons.

B. Management Approach

In organizing the alternate concepts, three categories have been established which represent different stages of technical development, designated as levels 1, 2 and 3. Level 3 represents the earliest stage of development, usually a new idea or an idea lacking experimental demonstration, where small experimental devices are used to provide some early basic tests of the approach. Level 2 is more advanced in terms of quality of the experiments, theoretical understanding, and reactor descriptions. Level 1 is a proof-of-principle experiment where most of the important dimensionless plasma parameters are in the reactor regime. A POP experiment is a high quality experiment with temperatures in the kilovolt range and $n\tau = 10^{12} - 10^{13} \text{ cm}^{-3} \text{ sec}$. (Such an experiment would roughly correspond to the scientific equivalent of PLT in the tokamak program).

As a result of the Concept Review Committee evaluations described elsewhere in this report, EBT has been selected as the first alternate concept to be developed to Level 1.

Previously EBT would have been designated as level 2. Other concept areas presently funded by the AFC Branch are: the RFP; linear magnetic fusion (LMF); Tormac; liners; multipoles (and advanced fuel cycles); stellarator/torsatrons; and a variety of field reversal approaches which are collected under the heading of "compact toroids." There are other ways in which to categorize the alternate concepts into groups, but the above list has proven to be serviceable. Each of these concept areas has been assigned a state of development (e.g. level 2 or level 3) for management purposes.

The following is a list of the eight concept areas in the alternate concepts program by level of development:

- LEVEL 1 ● Elmo Bumpy Torus (EBT) (in progress)

- LEVEL 2 ● Reversed Field Pinch (RFP)
 - Linear Magnetic Fusion (LMF)
 - Advanced Fuels/Multipoles (AF/MP)
 - Stellarator/Torsatrons (S/T)

- LEVEL 3 ● Compact Toroids (CT)
 - Linus
 - Tormac

Priorities have been established for these concepts by the Advanced Fusion Concepts Branch, and are regularly reviewed.

It is our intention for the alternate concepts program to be managed in a dynamic way. As definitive research results become available for a concept at any level, a decision will be made to either advance that concept to the next level or to terminate funding. Funding priorities among the various concepts will be based on reactor attractiveness, commercial potential, and technical and programmatic considerations. Periodic evaluations of all concepts at every level are conducted to ensure up-to-date information on which to base funding decisions. Funding may be terminated for some concepts considered less promising in order to provide program resources (i.e. funding and manpower) for new and more promising ideas.

As a final comment, we welcome proposals on new or on-going concept areas. In accordance with DOE policy, unsolicited proposals on alternate concepts may be submitted at any time to the Office of Fusion Energy.

The Office of Fusion Energy (ETM) is planning to broaden the base of the magnetic fusion program by fostering development of several of the most promising alternate fusion concepts. As part of this development effort, ETM plans to test one or two concepts experimentally at the proof-of-principle (POP) level. This document describes procedures to be used for concept selection, and is not to be construed in any way as a formal Request for Proposals. After concepts have been selected, all DOE procurement procedures and other regulations will be followed in selecting contractors to perform actual POP experiments. For present purposes, a POP experiment can be regarded as a hydrogen plasma confinement experiment in which nearly all of the relevant physics parameters such as collisionality, beta, etc., are near enough to the reactor plasma regime to allow a reasonable extrapolation. Such judgments are subjective, and specific requirements will vary from concept to concept. Typical plasma conditions for such an experiment might be an ion temperature in the keV range and an $n\tau$ product of 10^{14} to 10^{15} cm³sec. The fabrication of POP experiments in this alternate concepts development program would be initiated in fiscal year 1979 and completed by late fiscal year 1982 or early 1983. Alternate concepts which are to be tested at the POP level will be referred to as "level 1" concepts.

In addition to level 1 concepts, one or more concepts currently in a less developed research stage, which are not ready for a POP experiment, may also be selected for an accelerated development program. These concepts are identified as level 2 concepts. Some research on new concepts, or concepts in a more exploratory stage, i.e. level 3 concepts, will also be supported. An expected result of this selection process is that research on concepts considered less promising will be reduced or terminated.

ETM's alternate concepts program is the responsibility of the Division of Applied Plasma Physics (DAPP), and within DAPP, of the newly formed Advanced Fusion Concepts (AFC) Branch. Level 2 and level 3 concept selections will be carried out by the AFC branch during coming months as part of its overall program responsibility in the alternate concepts area. Candidate concepts for level 2 and level 3 development will include, but not be limited to, all confinement approaches presently supported in AFC programs. The selection process for POP level 1 experiments is described below.

The selection of concepts for advancement to the POP stage will be made from among those concepts which possess sufficient definite critical issues to allow specification of definitive tests. The methods and criteria by which this selection will be made are described in the following sections. It should be noted that the selection process described here will be a selection of concepts to be developed, and not a selection of either particular experiments or particular reactors. Presentation by interested parties is invited as one type of input for ETM in formulating its policies regarding the development of alternate concepts. Appropriate supporting experiments, theory, component development, and reactor studies will be initiated as necessary to develop complete POP level 1 programs after concepts have been selected.

Only concepts that currently have physics data base which is deemed sufficient to allow design of a POP experiment which has a reasonable capability of providing a definitive test that concept will be considered at this time. A concept requiring an intermediate experiment to define critical issues before a POP sized experimental test of these issues could be designed will not be considered as a candidate. (Such concepts may fit naturally into AFC development plan level 2 or level 3 activities.) In addition, any concept determined by previous DOE, ERDA, or AEC review to be technically unsound or not having sufficient potential for a viable fusion reactor will not be considered.

III. PROCEDURES TO SELECT CONCEPTS

Evaluation and recommendation of candidate concepts will be made by the Concept Review Committee consisting of members of DOE's Office of Fusion Energy. The Committee will be chaired by the Director of the Division of Applied Plasma Physics. Various Federal Government representatives (for example representatives of Energy Technology, Office of Energy Research and National Science Foundation) will be invited to attend as observers. The Committee plans to make recommendations to the Program Director, Office of Fusion Energy, by October 27, 1978. A more detailed schedule is given below in section VI.

A small group of technical consultants will aid the Committee, primarily in evaluating physics and technology issues. With the aid of the consultants, each concept will be evaluated by the Committee. The Committee will then formulate recommendations on initiation of an alternate concept level 1 program to the ETM program director. It should be noted that

Office of Fusion Energy

ALTERNATE CONCEPTS DEVELOPMENT PROGRAM

Meeting

SUMMARY

October 16-18, 1978, beginning at 10:00 a.m., a public meeting will be held by the Concept Review Committee of the Office of Fusion Energy, Department of Energy, at DOE, Germantown, Md. The purpose of gathering and discussing information on candidates for "level 1" alternate concepts. By alternate concept is meant a plasma confinement approach which does not fall within the mainline tokamak or stellarator fusion programs, and which appears to show promise for a fusion reactor. A level 1 alternate concept is a concept for which proof-of-principle tests, as defined below, will be carried out. Background information details of the meeting follow

formulations formulated by the committee may include significant changes in the development plans for selected concepts from those suggested by the proponents, in order to make the overall fusion R&D program more effective.

INSTRUCTIONS FOR PRESENTATIONS TO THE COMMITTEE

In order to assist the Committee in its decisions, the Committee will consider plans and suggestions for concept development which are presented to it by proponents of various candidate concepts. Presentation of material to the Committee will occur by two means: Written submissions and oral presentations before the Committee during the October 16-17 meeting. Written submissions should reach the Committee by October 7, 1978. Technical considerations and time constraints may limit the number and duration of oral presentations to the Committee.

One of the selection criteria mentioned in section V of this notice should be dealt with in the written submissions. It may be possible to present only a part of these criteria in the time available for oral presentations. The oral presentations should therefore be organized to present the most important information for the concept; elaborating obvious points (either strengths or weaknesses) will be the most effective use of time. The suggested format for oral and written presentations is given below:

FORMAT GUIDANCE FOR PRESENTATIONS TO COMMITTEE

Brief description of the reactor embodiment to be extracted from the 1977 Alternate Concepts report, if applicable. To include:

- 1) Specific reactor advantages;
- 2) Plasma parameters; and
- 3) Operational scenario (start-up, refueling, quenching, etc.).
- 4) Description of the present state of research and the existing physics data base, including international efforts. To include:
 - a) Experiments currently in operation, their parameters;
 - b) Experiments currently approved and under fabrication (expected plasma parameters and dates);
 - c) Status of theory; and
 - d) Scaling laws - overview.
- 5) Discussion of primary physics problems that need to be investigated in the next stages of development.
- 6) Description of the POP experiment facility:
 - a) Preliminary conceptual design;
 - b) Device parameters;
 - c) Expected plasma parameters;
 - d) Required technology and auxiliary systems; and
 - e) Cost and schedule.
- 7) Experimental program;
- 8) Specific physics issues to be investigated.

for upgrades or modification with the concept.

- a) Discussion of relation of this POP experiment to the mainline fusion program, i.e. tokamaks and mirrors.
- b) Suggested future devices and overall concept development plan.

Concept development plans should include a description of past, present, and planned devices for the concept under consideration, with a clear description of critical issues to be addressed in each device. In addition, there should be an assessment of the world-wide research effort in the concept area, and a specification of the cost, schedule, performance parameters, and hardware description of the proposed experimental facility. Clearly, a detailed POP experimental device design will not be available for this evaluation unless it was prepared at an earlier date for another purpose. Therefore, only a rough estimate of device characteristics and operating parameters may exist. However, the estimates must be justified on the basis of previously measured experimental data or reasonable theoretical estimates. The device hardware and associated power supplies must be specified sufficiently well to allow judgment of component development requirements.

All persons attending the meeting will have until October 23, 1978, to submit written comments on any of the concepts presented at the public meeting.

V. CONCEPT EVALUATION CRITERIA

The review of candidate concepts will be based on examination of the reactor desirability of the concept, confidence in achieving the critical physics tests, confidence in fabrication and operation of components of the POP experimental device to specification, and the relationship of the suggested POP experiment to the overall program plan for the concept. Cost and schedule information will also be considered.

One source of information for the Committee will be the Alternate Concepts Evaluation conducted by EIM in 1977 (EIM report "An Evaluation of Alternate Magnetic Fusion Concepts—1977", DOE/ET-0047 (May 1978)). New information developed since the 1977 evaluations, and also studies of alternate concepts by other groups such as the Electric Power Research Institute (EPRI), will be considered by the Committee. In conducting its review, the Committee will give appropriate weighting to the varying state of existing knowledge for the concepts. The committee will consider the various items of requested information from presenters (see section IV

for POP into three categories: Technical issues (see V.A, V.B, V.C) resource considerations (V.D), and programmatic issues, including a concept development plan (V.E). In more detail:

A. REACTOR DESIRABILITY

The concepts should exhibit features that could be developed into an attractive fusion reactor system. Reactor desirability will be an important criterion in the selection process. The time table for completing the concept review procedure is relatively short and there will be no opportunity to generate new reactor stories. Therefore, the evaluation will be made on the basis of existing information, recent alternate concepts report DOE/ET-0047, which will be available to the Committee, contains reactor descriptions of the concepts evaluated as well as the results of the evaluation itself. Consideration will not be restricted to concepts covered in the report.

B. EVALUATION OF THE ABILITY TO ACHIEVE TESTS OF CRITICAL PHYSICS ISSUES

The evaluation by the Committee will be based on the confidence which can be placed in the proposed POP experiment to address critical physics issues for the concept in a definitive way will be based on examination of physical assumptions with respect to the present data base and existing theory as well as the possible limits imposed on performance of the experiment by technology. The issues to be examined include equilibrium and steady-state transport, heating, impurities, and fueling.

C. EVALUATION OF TECHNOLOGY CONFIDENCE

The evaluation of the technology confidence for the concept will be based on an examination of individual components for development requirements beyond proven technology. Intermediate (non-reactor-relevant) technology will be acceptable (but preferred) for the POP experiment. A reasonable program plan can be presented to indicate how the reactor-relevant technology can be developed.

D. COST AND SCHEDULE

Fabrication schedules will be examined particularly for critical items that may potentially result in delays. Rough cost estimates for POP experiments, including development costs, will be examined for

E. RELATIONSHIP TO CONCEPT DEVELOPMENT PLAN

Each proposed POP experiment will be evaluated on the basis of its relationship to past, present, and planned experiments described in the requested development plan for the concept. Some questions to be considered by the Committee are: Does the suggested experiment constitute a true POP test? What supporting experiments in the U.S. or other countries are operational or planned that can contribute to the development of the concept? Recognizing that significant information about a concept can be gained from experiments on a different concept, can the proposed experiment be expected to provide a significant extension of plasma parameters and new physics knowledge beyond that obtained in other experiments which are either operational or under fabrication?

VI. SCHEDULE FOR CONCEPT SELECTION

All persons or organizations wishing to make an oral presentation to the Committee at the October 16-18, 1978 meeting, are requested to notify ETM in writing by September 5, 1978, so that a timely agenda can be prepared. This notification should include a short (no more than one page) summary description of the POP experiment to be described to the Committee with basic objectives, parameters, cost, and schedule. An agenda will be prepared based upon the responses. Technical considerations and time constraints may limit the number and duration of oral presentations. A fairly tight schedule for oral presentations at the October meeting is anticipated. Participants will be notified by mid-September.

An estimate of the attendance at the October meeting, including observers, is needed. If you plan to attend, please notify ETM by September 15 so that plans can be made for a suitable meeting room.

REVIEW SCHEDULE

● ETM initial mailing of announcement.....	Aug. 11, 1978.
● ETM announcement in FEDERAL REGISTER.....	Approximately Aug. 28, 1978.
● Persons desiring to make oral presentations notify ETM and submit summary descriptions of POP experiment.....	Sept. 5, 1978.
● Tentative agenda established.....	Sept. 15, 1978.
● Persons planning to attend notify ETM.....	No.
● ETM receives written submissions for committee.....	Oct. 7, 1978.
● Public meeting—committee hears oral presentations.....	Oct. 16-18, 1978.
● ETM receives comments from attendees.....	Oct. 23, 1978.
● Committee makes recommendations to ETM director.....	Oct. 27, 1978.

Communications may be addressed to William P. Ellis, Chief, Advanced

Fusion Concepts Branch, Division of Applied Plasma Physics, Office of Fusion Energy, U.S. Department of Energy, Washington, D.C. 20545, telephone: FTS 233 3563, Commercial Area Code 301-353 3563, or to any member of the Advanced Fusion Concepts Branch if Dr. Ellis is unavailable.

Issued in Washington, D.C., August 24, 1978.

WILLIAM S. HEFFELINGER,
Director of Administration.

FER Doc. 78 24368 Filed 8-28-78, 8:45 AM

APPENDIX B
OPENING REMARKS BY CRC CHAIRMAN

"My name is Jim Decker and I am from DOE's Office of Fusion Energy. I would like to welcome all of you and thank you for coming to participate in DOE's Review of Alternate Magnetic Fusion Energy Concepts. The purpose of this meeting is pretty well described in material that was sent to most of you and also in an article that appeared in the Federal Register. If you do not have copies of either the material that we sent out or the Federal Register article, there are copies of the Federal Register article available. Before we start on our agenda this morning, I would like to review some of the rationale for what we are doing to help bring some perspective to the meeting.

The Department of Energy's recently established policy on magnetic fusion energy places emphasis on accelerated development of a few promising alternative magnetic confinement concepts so that comparisons can be made between those alternatives and tokamaks and mirrors in the mid-1980's.

What do we mean by concepts that are promising? In light of recent results from the tokamak program, particularly the PLT results, the fusion community and the Department of Energy are confident that breakeven conditions or scientific feasibility will be demonstrated by tokamaks. In other words, we feel that it is very unlikely that an alternative concept will be needed to demonstrate scientific feasibility. Consequently, when we say promising alternatives we mean those concepts that show the most promise of providing significant advantages over tokamaks and those concepts in which we have a reasonable degree of confidence in their successful development.

In order to make realistic comparisons between alternative concepts and tokamaks and mirrors in the mid-1980's, it will be necessary to establish a sound scientific data base for the alternative concepts to make those comparisons. It is clear that between now and the mid-1980's some real experimental tests of some of the alternate concepts are needed. We call these real tests physics proof-of-principle experiments. It is probably not possible to define proof-of-principle precisely in a way that would cover all magnetic fusion concepts. On the first viewgraph, we have attempted a rough definition. In such an experiment, most of the important dimensionless parameters would be in the reactor regime. Some examples of important dimensionless parameters might be collisionality, the ratio of Larmor radius to a plasma dimension, etc. For most concepts this requirement is likely to lead to plasmas with ion temperatures in the kilovolt range and n_T in the 10^{12} to perhaps 10^{13} range. The proof-of-principle experiment might be looked at as the scientific equivalent of

PLT in the tokamak program. For most concepts a proof-of-principle experiment will be a sizeable undertaking. Consequently, it is necessary to initiate proof-of-principle experiments in the next couple of years if concept comparisons are to be made some time in the mid-1980's.

We have organized our initiation of proof-of-principle experiments into a two-step process as shown in the next viewgraph. The first step is concept selection which is essentially the making of policy within the Office of Fusion Energy and DOE. The second step is contractor selection for fabrication and operation of actual experiment. Any proposals for new work in alternate concepts received before the concept selection is completed will not be evaluated. In fact, it is our intention not to even read such proposals during this period. After concepts have been selected, all DOE procurement procedures and other regulations will be followed in selecting contractors to perform actual POP experiments. At the present time, we are working on the first step, concept selection only. This meeting is part of that process.

The organization of our concept selection process is shown in the next viewgraph. This present review of alternate concepts for Level 1 or Proof-of-Principle Experiments is being conducted by what we call the Concept Review Committee. This Committee consists of DOE personnel. I will list the membership of that Committee later. The Concept Review Committee will make recommendations to the Director of the Office of Fusion Energy, and it will be the responsibility of the Director of the Office to make the final decision on concept selection. The Concept Review Committee will make its recommendations based on input from proponents of various concepts, a group of technical consultants, some internal DOE advisors, and from the public.

The next viewgraph shows the membership of the Concept Review Committee. I am chairing the Committee. Other members from the Office of Fusion Energy include Bill Ellis, Chief of the Advanced Fusion Concept Branch, Bill Dove and Erol Oktay, both of whom work in Bill Ellis' branch. We also have Ron Kostoff from the Office of Energy Research and Jim May from the Office of the Assistant Secretary for Energy Technology. Our advisors are all from the Office of Fusion Energy. They are listed on the next viewgraph. Each of the divisions within the Office of Fusion Energy are represented.

The next viewgraph lists our technical consultants. We have a mixture of plasma physicists, engineers and utility representatives.

The schedule for the concept review is shown on the next viewgraph. We have completed all of the items down to the third from the bottom which is where we are today. Any comments that any of you may have should be sent to us in writing so that we receive them by October 23. The Concept Review Committee will make its recommendations to the Director of the Office of Fusion Energy by October 27. However, the recommendations will not be made public at that time since further internal DOE review of the selection process will take place.

Some of you may be asking yourselves what are the possible outcomes of this review.

It seems to me that there is a wide spectrum of possible recommendations that the review committee could make. Perhaps one extreme is that several concepts are highly promising and are ready for immediate POP tests. The other extreme is that none of the concepts are ready or perhaps sufficiently promising that a POP experiment should be initiated at this time. Of course a large number of recommendations between these two extremes are possible. Let me assure you that DOE is taking this exercise very seriously and hopes to be able to move ahead with the alternate concepts program in a vigorous fashion.

Some of you may be wondering what will happen to our present alternate concepts program if a decision is made to proceed with one or two large experiments. It is my expectation that the program will become somewhat more focused and research on some concepts considered least promising may be significantly reduced or terminated. However, it is not our intention to concentrate solely on those concepts at the level 1 or POP stage. We will also continue to support research on some promising concepts that are at Level 2, i.e., they are in earlier stages of development. I want to remind you that we are not considering concepts for Level 2 research at this time, but only level 1 POP experiments.

That concludes the remarks that I wanted to make this morning. I look forward to a very interesting three days of presentations. Phil Stone will act as the presiding officer for the remainder of the meeting. I have asked Phil to assume this task so that I and other members of the Concept Review Committee can concentrate on the presentations and pertinent discussions. In a similar spirit, you should recognize that members of the Concept Review Committee will not be available for discussions that are not directly relevant to this review."

RECOMMENDATIONS OF THE CONCEPT REVIEW COMMITTEE ON SELECTION OF ALTERNATE CONCEPTS FOR PROOF-OF-PRINCIPLE PROGRAMS

Introduction

The recently announced DOE policy on the development of fusion energy places increased emphasis on the testing of promising alternate concepts. More specifically, this policy suggests comparisons of promising alternatives with tokamaks and mirrors in the mid-1980's. In order to make these concept comparisons, it is necessary to greatly extend the scientific data base for the alternate concepts toward the reactor regime to provide significant experimental tests. These significant tests have been designated as proof-of-principle (POP) experiments and have most of the important dimensionless parameters in or near the reactor regime. A POP experiment for an alternate concept can be considered the scientific equivalent of PLT in the tokamak program.

A DOE Concept Review Committee (CRC) was established to examine candidate concepts for POP experiments and to make recommendations to the Director of the Office of Fusion Energy on concept selections for initiation of POP experiments to begin operation in 1982-1983. The Office of Fusion Energy solicited nomination of concepts for POP consideration from contractors, noncontractor institutions known to be interested in magnetic fusion and the general public via mailings and with an announcement in the Federal Register. Written material on candidate concepts was submitted to the CRC and its advisors and technical consultants by proponents and other interested parties. Oral presentations were heard from concept proponents in a public meeting on October 16-18, 1978. A wide spectrum of recommendations seemed possible — one extreme being that several concepts are very promising and are ready to make the move immediately to a POP experiment; another extreme being that no concept is sufficiently advanced or promising to be recommended for a POP program at this time. The whole spectrum of possible recommendations between those two extremes was considered.

Following the public meeting, the technical consultants and advisors provided technical advice to the CRC by answering specific questions on: (1) the reactor desirability of the concept, (2) the physics and technology confidence for both the reactor and the POP experiment, and (3) cost and schedule data for the POP experiment. Based on consideration of these three areas and some programmatic issues, the CRC has developed the findings and recommendations contained in this document.

Discussion of Results

A total of nine concept areas were presented to the CRC for consideration. These nine were the:

- (1) Elmo Bumpy Torus (EBT)
- (2) Torsatron/Stellarator
- (3) Reversed Field Pinch (RFP)
- (4) Linear Magnetic Fusion (LMF, including solenoids and wall confined linear multiple mirrors)
- (5) Ion Rings
- (6) Pyrosphere
- (7) Diweller
- (8) Plasma Mantle-Kernel (PMK)
- (9) Multipole/Surmac

The EBT, torsatron/stellarator, RFP, and multipole/Surmac had more than one institutional proponent and in these cases different approaches to the POP experiments were discussed. The CRC believes that all alternate concepts which are serious contenders for a POP-level test at this time were considered in this review.

Our evaluation of the candidate concepts resulted in a division of the concepts into three categories: (I) concepts judged to be potentially eligible for a POP experiment by an overwhelming majority of the CRC and its consultants and advisors, (II) concepts where readiness for POP experiments at this time is more questionable, and (III) concepts judged definitely not ready for POP experiments. The recommendations and discussions which follow are limited to those concepts potentially ready to proceed to a POP experiment now, i.e., concepts in categories I and II. Our findings are that two concepts (EBT and RFP) fall into category I, and two concepts (torsatron/stellarator and LMF) fall into

The remainder of this report will concentrate on the concepts in category I, namely EBT and RFP. These concepts have been examined critically in three areas:

- Reactor desirability of the concept
- Confidence in physics and technology assumptions for the proposed POP experiments
- Programmatic considerations

In assessing reactor desirability, the following issues, among others, were considered: (a) special features of the reactor, (b) special considerations for advanced fuels or fusion/fission applications, (c) overall assessment of reactor attractiveness, and (d) comparison with existing tokamak reactor designs. (With regard to the latter, the perceived problems of tokamak reactors as identified in the September 1978 DOE policy statement on fusion were specifically considered and addressed.)

A. EBT Discussion

We conclude that EBT offers a number of features that potentially may lead to an attractive fusion reactor. Among these are: steady state operation, modularity, easy access for maintenance, simple magnetics, absence of axial current (i.e., removal of one source of free energy), absence of disruptions, and potential availability of several heating options. Some disadvantages of an EBT reactor are: scaling laws which may preclude small unit sizes (i.e., less than 750 MWe), possible difficulties with ash and impurity control which could preclude steady state operation, and the necessity of driving the rings continuously. The EBT reactor was judged to be attractive in DOE's 1977 evaluation of alternate concepts and was again judged to be so by the CRC's consultants. The EBT reactor shows promise for overcoming some of the alleged disadvantages of tokamak reactors, namely pulsed operation, poor access, and difficult maintenance.

Examination of the proposed POP experiments indicates that the critical physics issues of the EBT concept are well defined and that the POP experiment can be designed to test all or nearly all of the critical issues. Further important experimental results from EBT-S are expected in the near future. The main technology concern of the POP experiment which could adversely affect the schedule is the development of high power, high frequency (~ 100 GHz) CW gyrotrons for electron cyclotron plasma heating (ECRH).

There are several important programmatic considerations associated with initiation of an EBT POP experiment. At the present time, only two bumpy torus devices employing EBT features exist, EBT-S at ORNL and a bumpy racetrack device at Nagoya, Japan. The U.S. program has pioneered this concept and to our knowledge there are no plans to initiate large POP-type EBT experiments in other countries to make major contributions to the development of this concept. There are several spinoffs from an EBT POP experiment that would benefit the rest of the U.S. magnetic fusion program: (1) the high frequency gyrotrons would be useful for tokamaks and other concepts; (2) operation of a significant sized toroidal system with superconducting toroidal field magnets would benefit other toroidal concepts; and (3) steady-state operation of a confinement device with hot fusion-grade plasmas would address physics and technology issues associated with long-pulse device operation.

B. RFP Discussion

The RFP was examined similarly. An RFP reactor was found to have certain attractive features such as the possibility of ohmic heating to ignition, batch burn capability (which eases refueling and ash removal), low stresses on the superconducting coils, better accessibility than tokamaks, and low probability of disruptions. However, there are some offsetting disadvantages: a single heating method (ohmic) with no viable backups at this time, the requirement of an efficient energy transfer system, the need for feedback control during startup, the close proximity of the Cu shell to the plasma, anticipated difficulties with cyclic fatigue, and uncertainties in how to control wall impurities. The net result is that, while the RFP reactor may offer some significant alternatives, it does not appear to offer clearly substantial engineering advantages over tokamaks. This assessment could change if RFP physics experiments prove very successful and/or innovative engineering designs improve the reactor configuration.

The RFP POP experiment as discussed by LASL personnel, would test, among other issues, the physics of establishing and maintaining a reversed field configuration by self reversal. The consensus of the CRC, and its consultants and advisors, is that a large experiment will be required to test these ideas and that a device capable of axial currents in the several megamperes (MA) range is necessary. LASL is recommending an aggressive experiment in the 6 MA range.

There are existing RFP research programs in Japan, the U.K., Italy and the U.S. Small devices have been or are operating in each country. The U.K. and the U.S. are each fabricating moderate sized devices; the U.K., HBTX-1A (0.4 MA) at Culham, and in the U.S. ZT-40 (0.6 MA) at LASL. In addition, Culham is now awaiting final U.K. government approval of funds to initiate fabrication of a new, larger experiment (RFX) with an initial current capability of 0.5-1 MA. The physics of the RFP configuration is related to that of other axisymmetric toroidal concepts such as the tokamak and spheromak. Some of the physics learned from an RFP POP experiment would undoubtedly aid the development of such related concepts.

Recommendations

EBT

In the alternate concepts program, the CRC finds the EBT to be the most ready for a POP test at this time. We find the EBT to be a truly alternate toroidal concept, and to have desirable reactor features that potentially make it more attractive than a tokamak. We believe that an EBT POP experiment will provide several important programmatic benefits to the rest of the fusion program, through operation of a steady-state, hot plasma confinement device, operation of superconducting toroidal field magnets, and the development of high frequency and radio frequency heating. The CRC thus recommends initiation of an aggressive but systematic course of action leading to an EBT POP experiment. We recommend (1) expansion of the existing theoretical, experimental and reactor study programs, (2) initiation of design activities for an EBT POP experiment, and (3) support for the necessary gyrotron development.

The ideal size and form for an EBT POP experiment remains to be determined. We recommend that design studies proceed assuming that the scheduled near-term EBT-S scaling studies and Aspect Ratio Enhancement (ARE) coil tests will be successful. The design studies should allow for ECRH heating and also direct ion heating capabilities, including rf and neutral beams. The possibility of an early test of rf ion heating on EBT-S should be examined. No funds should be committed to POP device fabrication until all device options have been thoroughly examined and agreement is reached on basic design features. A thorough peer review of the proposed POP experimental facility should be conducted. The most expensive of the EBT POP designs considered by the CRC was the one by ORNL, with POP experimental facility and gyrotron development costs estimated at between \$50M and \$70M over 4-5 years. We recommend that all available cost-saving methods be given close scrutiny, including technical descoping options and utilizing existing buildings, to reduce the required DOE funding commitments.

B. RFP

The CRC finds the RFP to be less attractive overall than the EBT as a reactor concept. The RFP does offer the potential advantage of ohmic heating to ignition, and is of considerable interest from a physics viewpoint. Specifically, the RFP configuration is near a minimum energy state for the combined plasma/magnetic field system and may well provide important, fundamental information on axisymmetric toroidal confinement configurations (of which the tokamak is one) which could change our approach to reactor designs for such systems. However, taking all factors into consideration, it is our recommendation not to initiate a large RFP POP program in the U.S. at this time.

Because of its potential contribution to the fusion program, we recommend that research on the RFP be continued at LASL with the completion and operation of the ZT-40 device. The Advanced Fusion Concepts Branch will work with LASL to reexamine the goals of ZT-40 to assure maximum relevance to the RFP program as it is now understood. Future RFP devices in the U.S. would be dependent upon results from ZT-40 and the world-wide status of the RFP concept.

In the U.K. the RFX device at Culham (estimated cost ~\$20M) is awaiting final approval. The next step in the RFP program, beyond ZT-40 and HBTX-1A, might be adequately filled by RFX, either as presently designed (≤ 2 MA), or possibly upgraded for operation at 2-4 MA. We recommend that cooperation between the U.S. and the U.K. (or Euratom as appropriate) be explored for RFP research and RFX in particular. A wide range of cooperation should be considered. At a minimum, personnel could be exchanged. A maximum cooperation might include direct U.S. support for RFX in the form of diagnostics or other hardware items as well as personnel. If a substantial U.S. contribution to RFX is to be made, the CRC recommends that a redesign of RFX to carry up to 3-4 MA be considered as a step to ensure a true POP-level test of the concept. Such a cooperative arrangement might solidify a large RFP experiment for the worldwide fusion effort with a relatively modest expenditure of U.S. resources.

SIGNATURES OF CONCEPT REVIEW COMMITTEE:

James F. Decker 10/30/78
 James F. Decker, Chairman
 Office of Fusion Energy

William R. Ellis 10/27/78
 William R. Ellis
 Office of Fusion Energy

William F. Dove 10/30/78
 William F. Dove
 Office of Fusion Energy

Erol Oktay 10/30/78
 Erol Oktay
 Office of Fusion Energy

James W. Mayo 11/2/78
 James Mayo
 Office of the Assistant Secretary
 for Energy Technology

Ronald N. Kostoff
 Ronald Kostoff
 Office of Energy Research